



MICROWAVE RADIOMETRY AND NOISE STANDARDS AT NIST

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Radio Frequency Technology Division
NIST, Boulder

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Cast:

- Engineers: George Free & Dave Walker
- Technicians: Rob Billinger & Andy Terrell
- Typical division of labor.

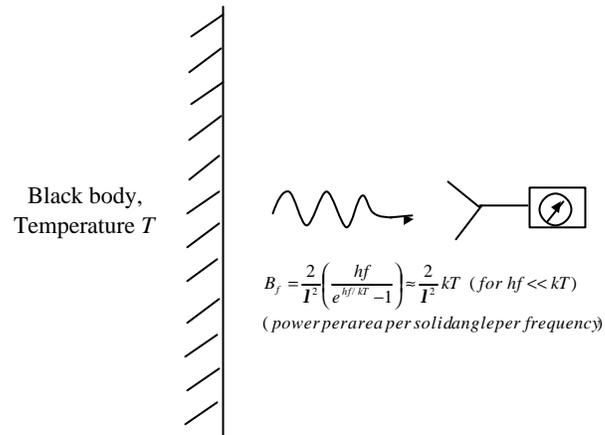
0. PRERAMBLE

- In principle, practice for talk at IMS Workshop on “Microwave & Millimeter-Wave Radiometry: State of the Art & Future Trends”
- In practice, talk is prepared, may as well give it somewhere.
- Different audiences, so will include a (very) brief remote sensing radiometry background.

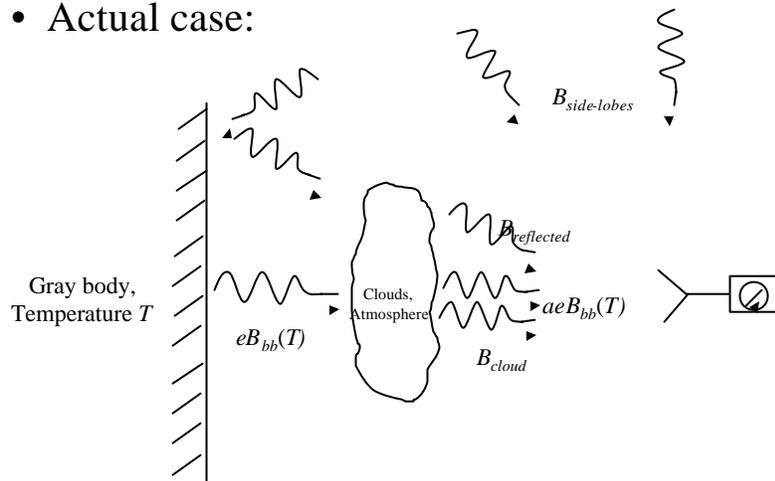
Background:

- Interested in microwave remote sensing of earth from satellites and airplanes.
 - Satellites: 24/7
 - Airplanes: verification (check) of satellite data, also for separate measurements.
 - Also other verification: sensors on earth
- Radiated power measurements. Various uses:
 - climate monitoring
 - weather modeling and forecasting
 - agriculture (moisture content)
 - ...

- Ideal case:

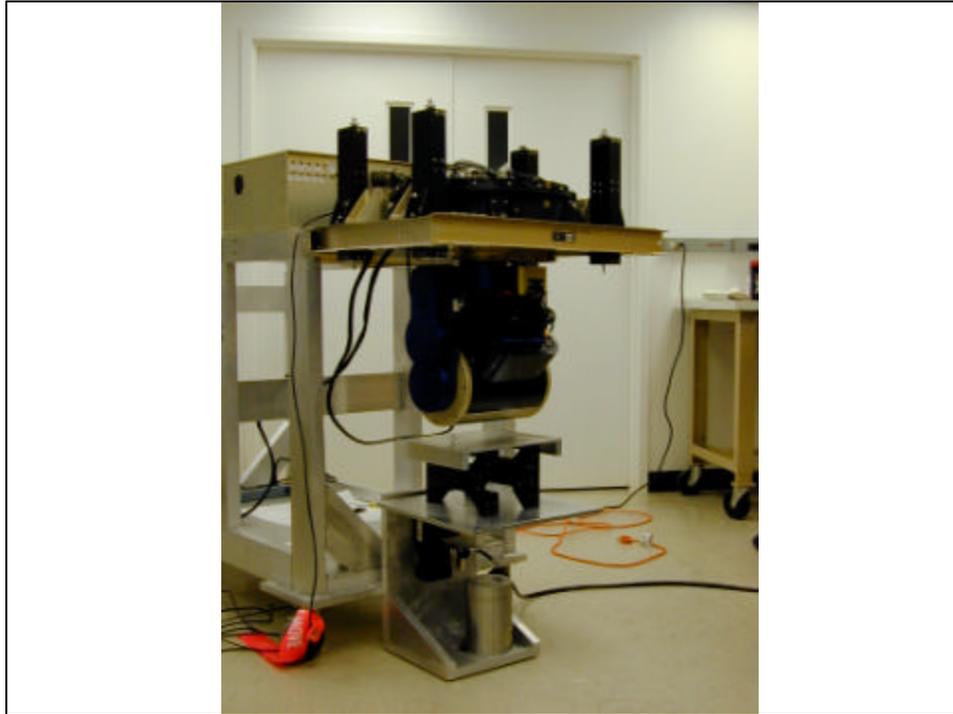


- Actual case:



- Calibration
 - both relative and absolute calibration important
 - cal before, during, after flight (where possible)
 - radiometers are designed to be linear,
 $p(\text{out})=a+b \times p(\text{in}) \Rightarrow$ need (\geq) two standards for calibration.
 - satellites: cold sky, if possible
 - otherwise: hot & cold targets, or injection.
 - need independent cal of targets, comparison to other radiometers, traceability.
 - NIST Optical Tech. Div. has such a program for Optical & IR.
- *e. g.*, CoSMIR





I. INTRODUCTION



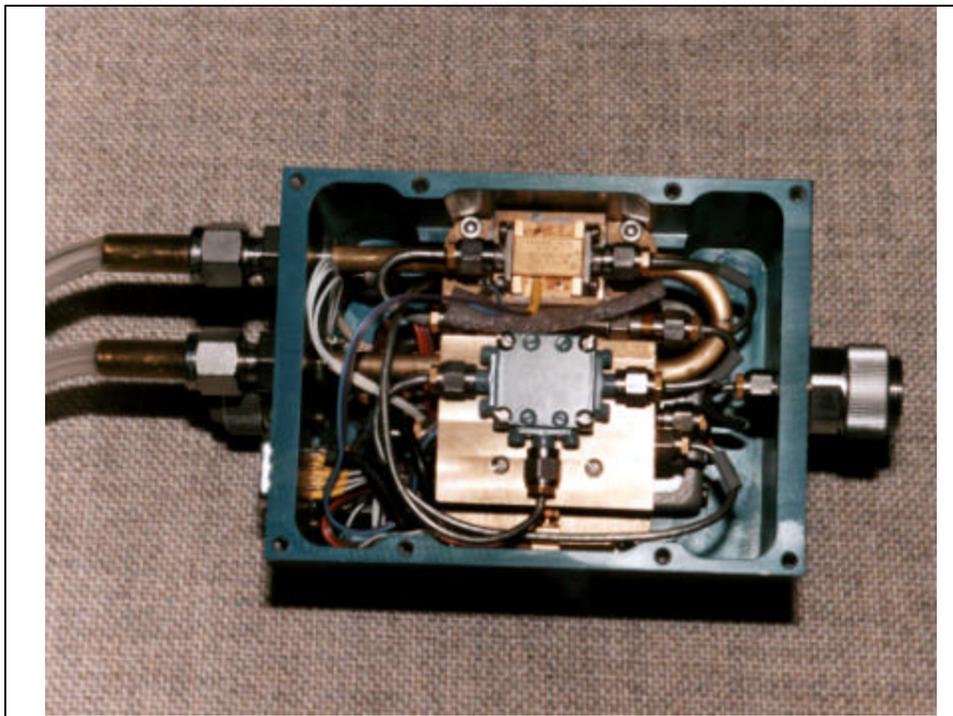
- Group has been measuring noise temperature in waveguide & coax for > 30 yrs.
 - Radiometers for coax & waveguide noise sources
 - Primary noise standards (cryogenic)
- More recently, noise parameters.
- Most recently, have begun extension to remote-sensing radiometer calibration (with antenna group). **Intend to convert (reversibly) radiometers to remote-sensing, to calibrate/check calibration targets.**

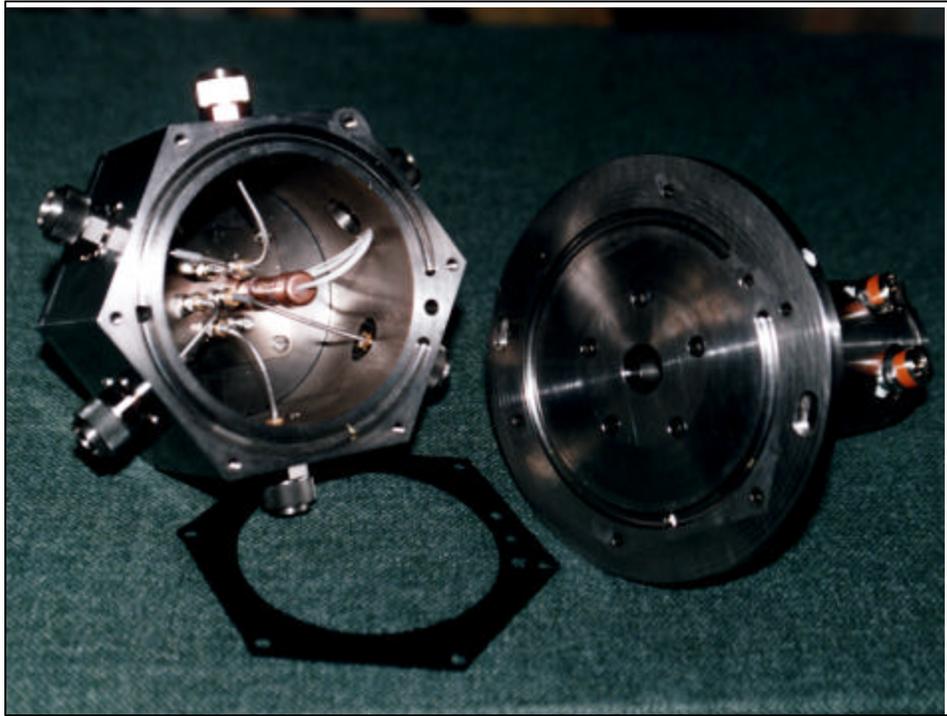
OUTLINE

- ✓ Introduction
- Traditional Activities
 - Radiometers (description & testing)
 - Standards
- Remote Sensing
 - Link to primary standards & traceability
 - Uncertainties
 - (nonlinearity)
 - target reflectivity
 - (general form)
 - (Standard definitions of commonly used terms)

II. TRADITIONAL ACTIVITIES

- Noise temperature of coaxial & waveguide noise sources in the lab.
- Radiometers:
 - at & above 1 GHz, isolated total-power radiometers. (Also cover 30 & 60 MHz.)
 - waveguide: 8.2 - 65 GHz, with built-in 6-ports
 - coaxial: 1 - 12.4 GHz, VNA + lookup table for reflection coefficients. (12.4 - 40 GHz through adapters on W.G. radiometers.)

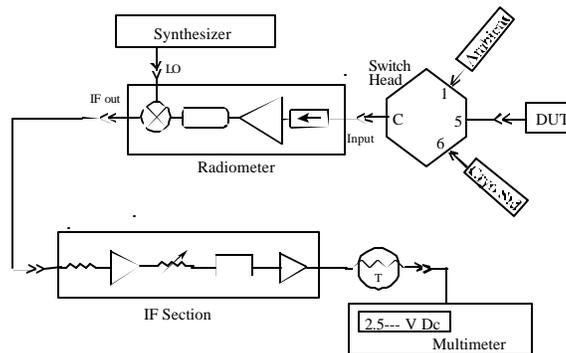




• Coaxial Radiometer, General Features:

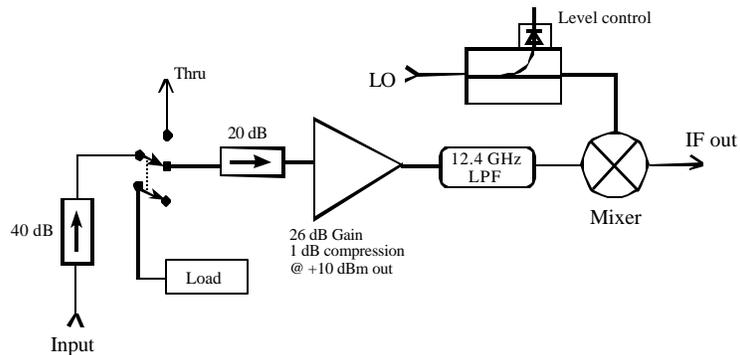


- Total-power radiometer, isolated (60 dB), baseband IF, double sideband, 5 MHz BW, thermistor detector.



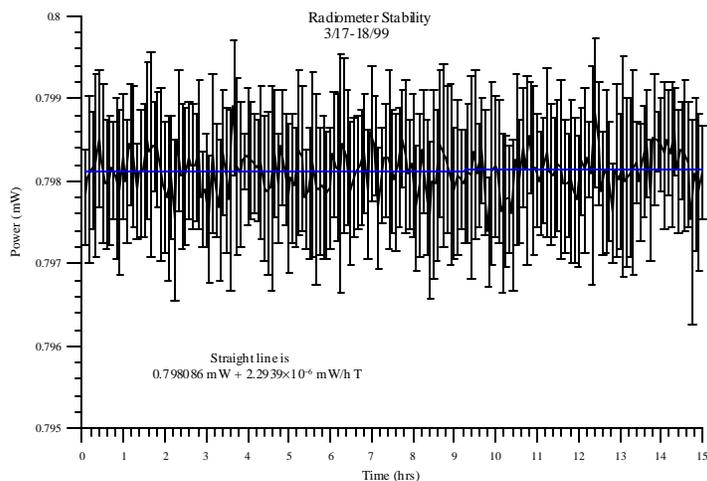
– Radiometer eqn:
$$T_x = T_a + \frac{M_{Cryo} h_{Cryo,0}}{M_x h_{x,0}} \frac{(Y_x - 1)}{(Y_{Cryo} - 1)} (T_{Cryo} - T_a)$$

- RF Section (8 - 12.4 GHz unit):

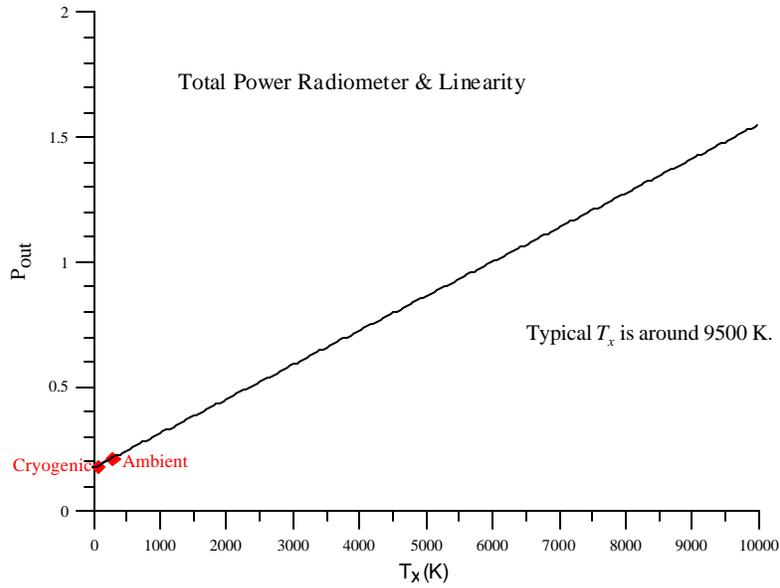


Some Characteristics & Tests

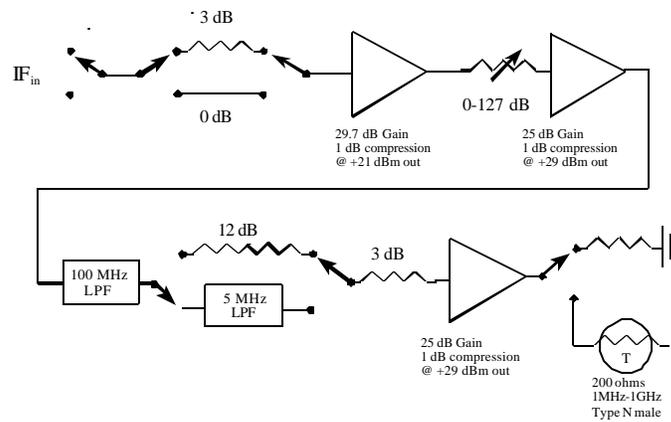
- Stability



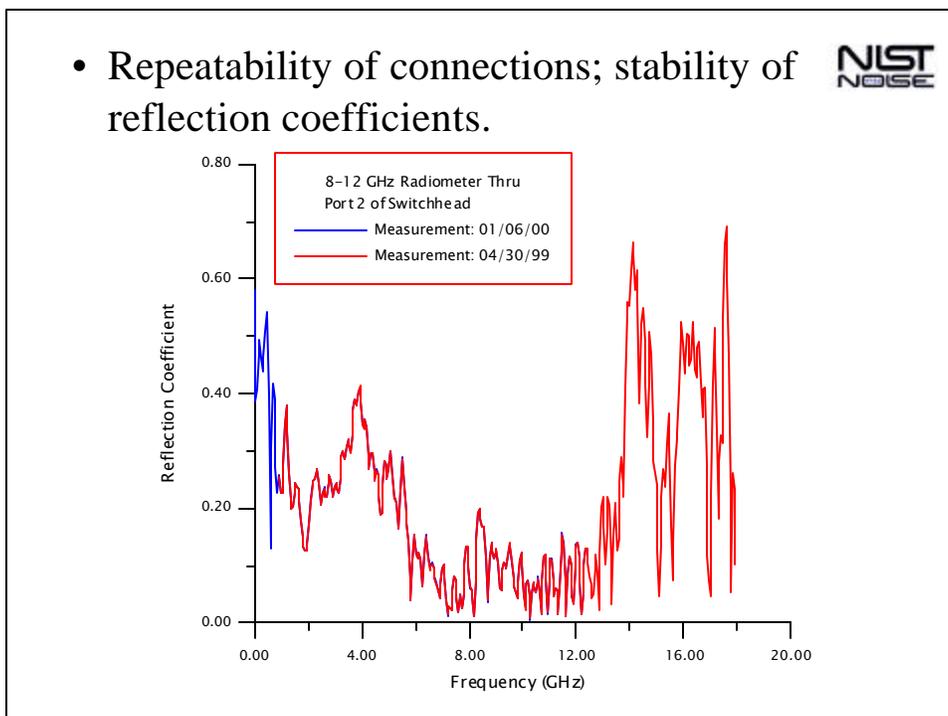
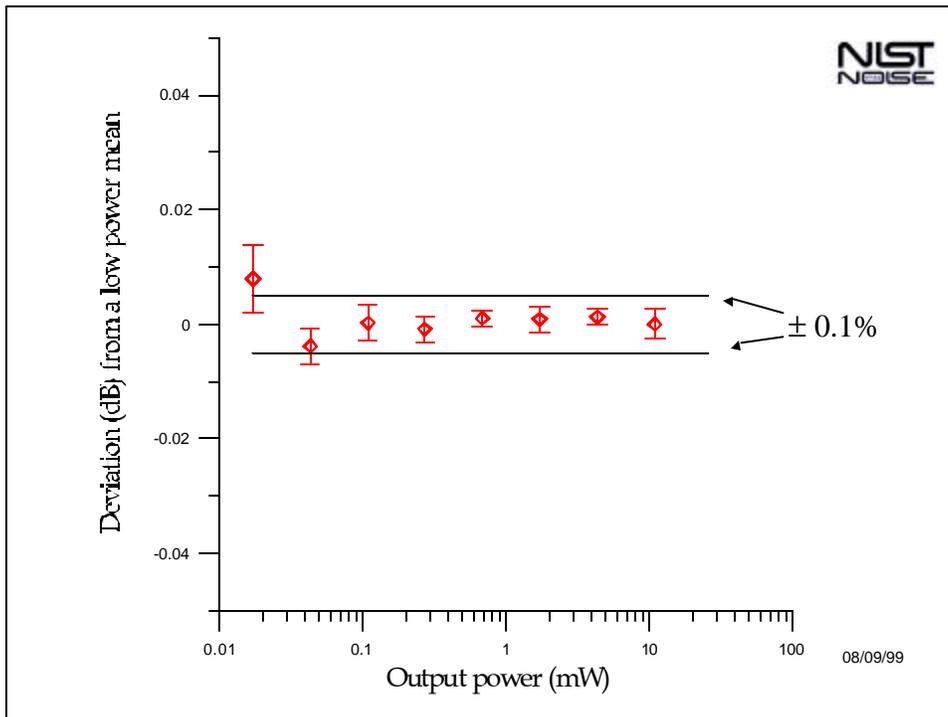
- Linearity is critical



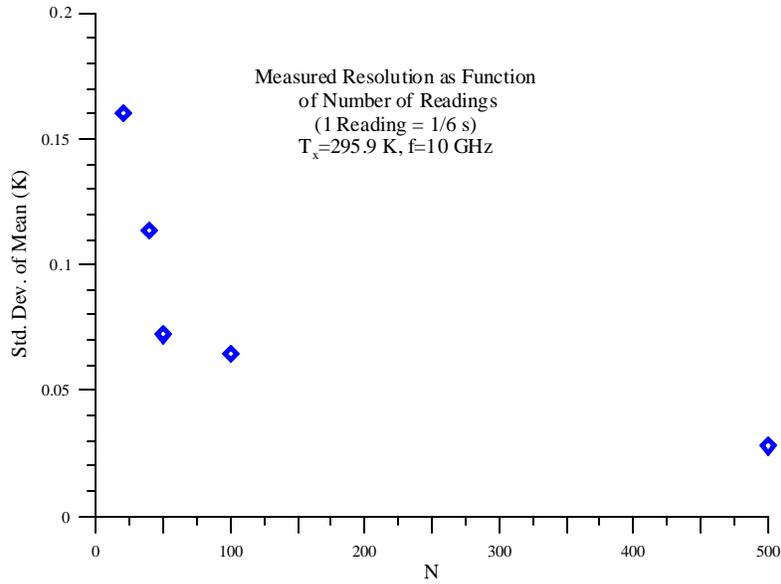
IF Section



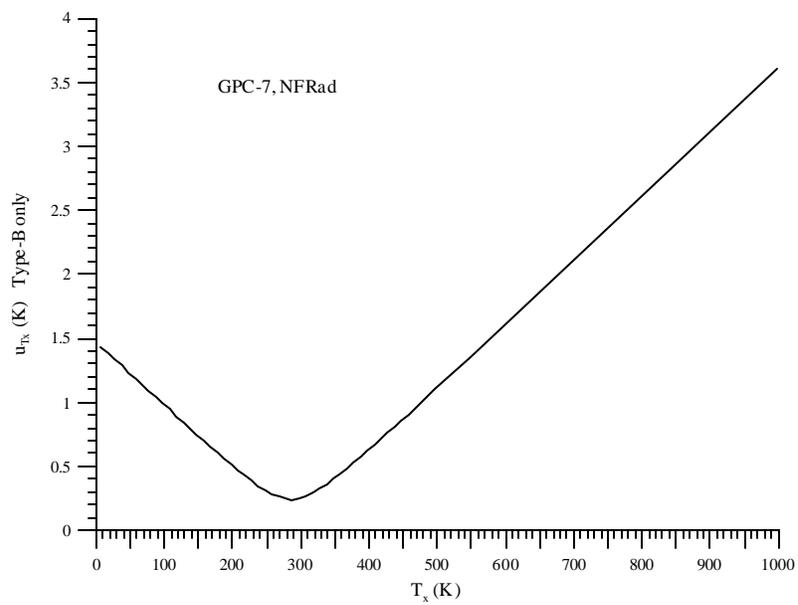
IF Linearity Test: measure with 3 dB attenuator in & out for range of 127 dB attenuator.



• Resolution



• Uncertainties (Type-B)

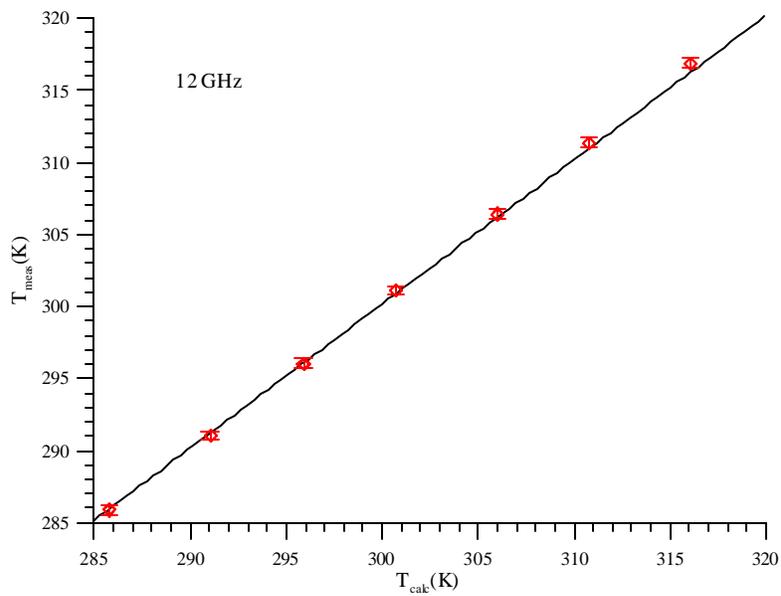


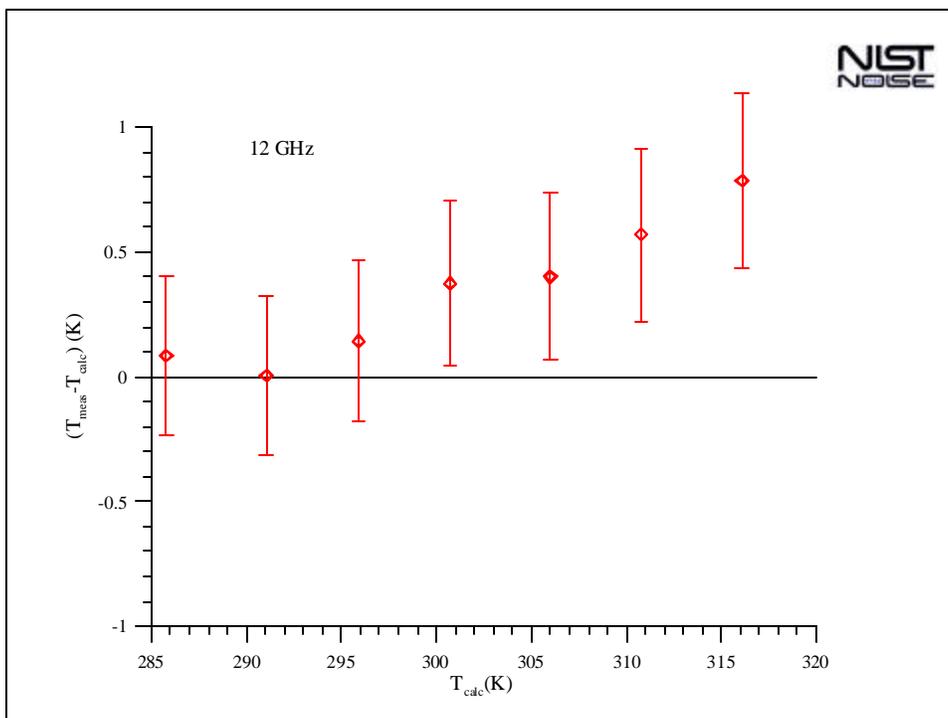
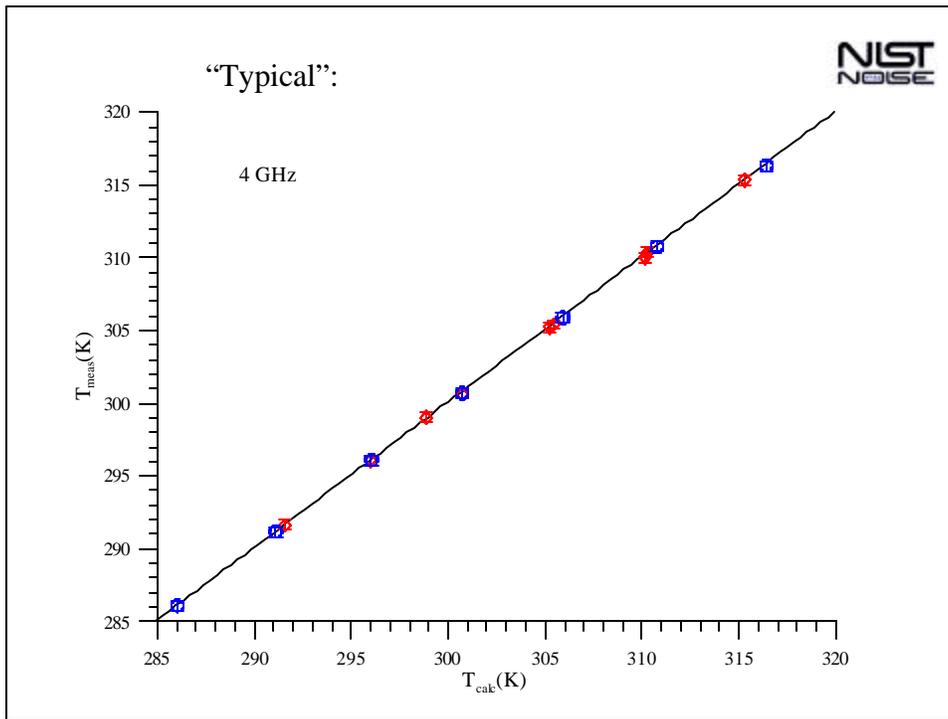
- Check of uncertainty near ambient:
 - Designed & built variable source with known noise temperature.

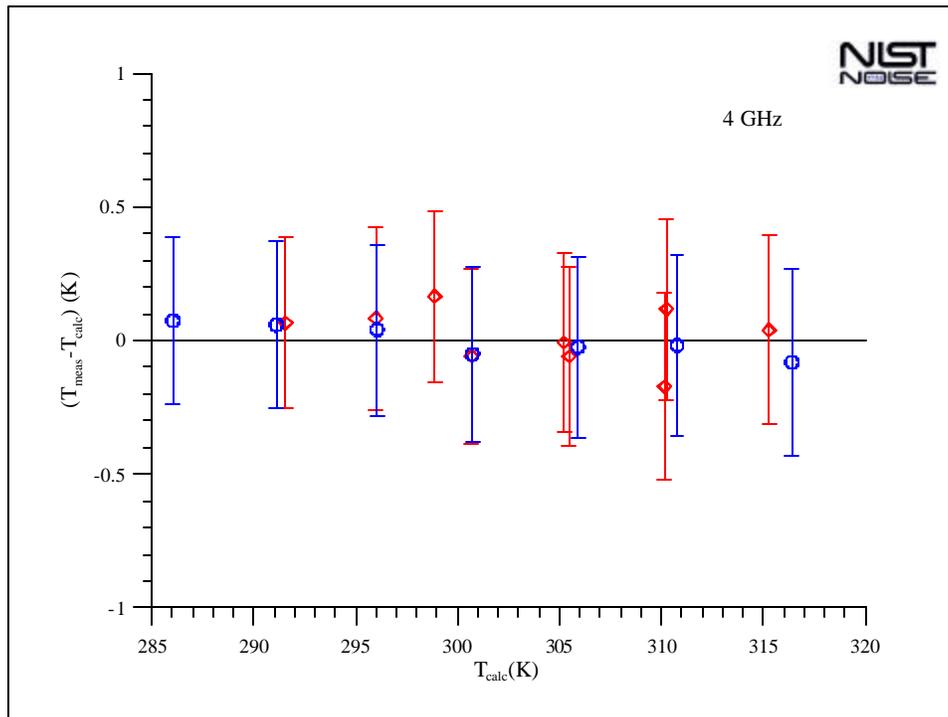


- Measured it.

Worst case:



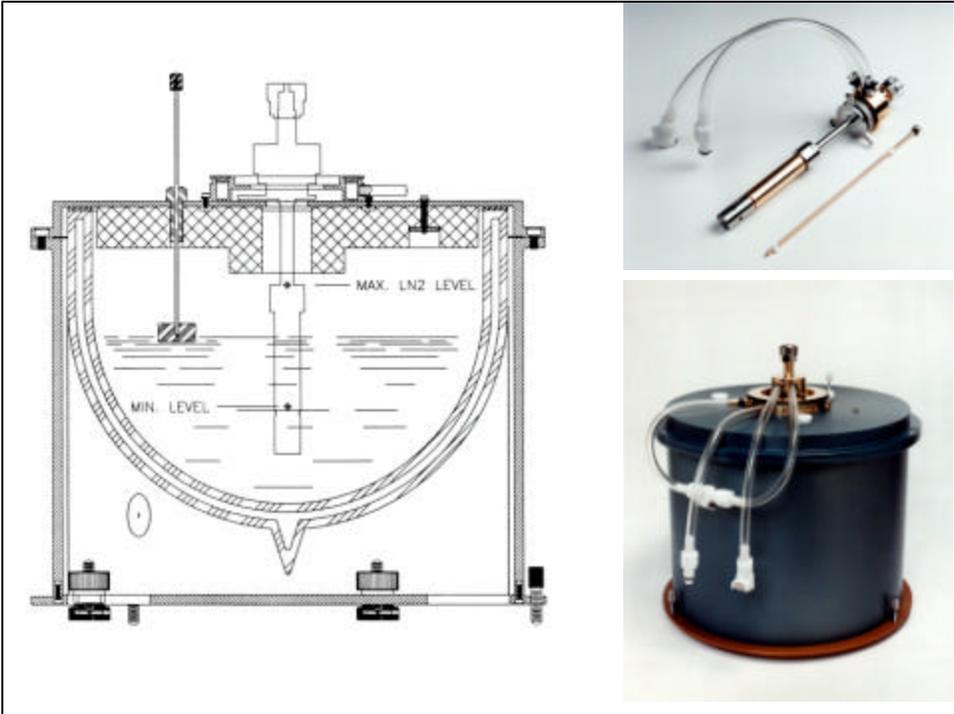
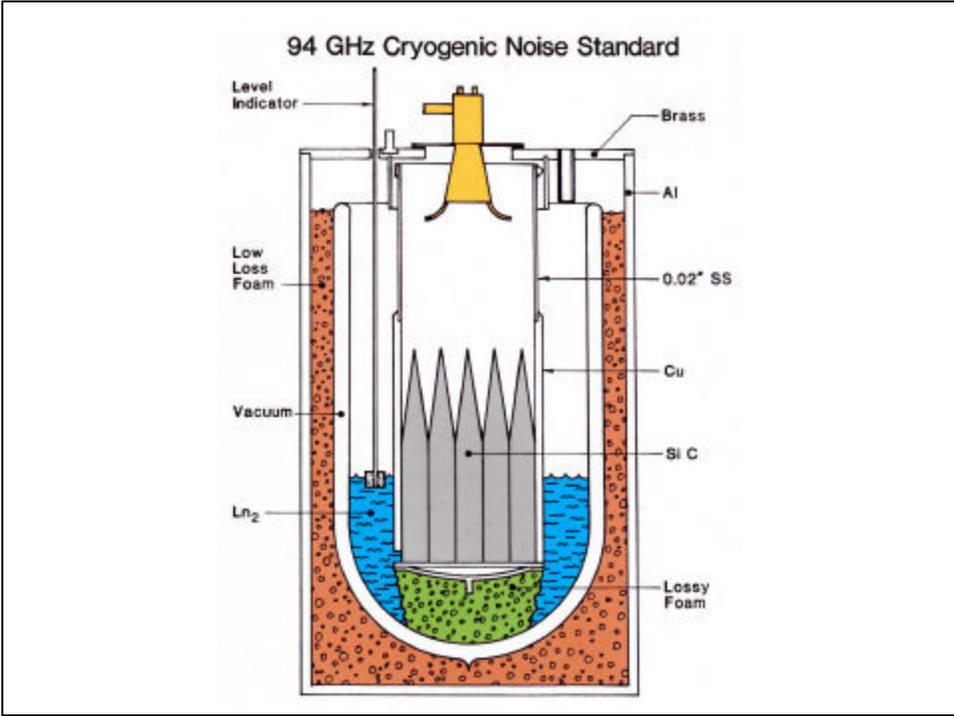


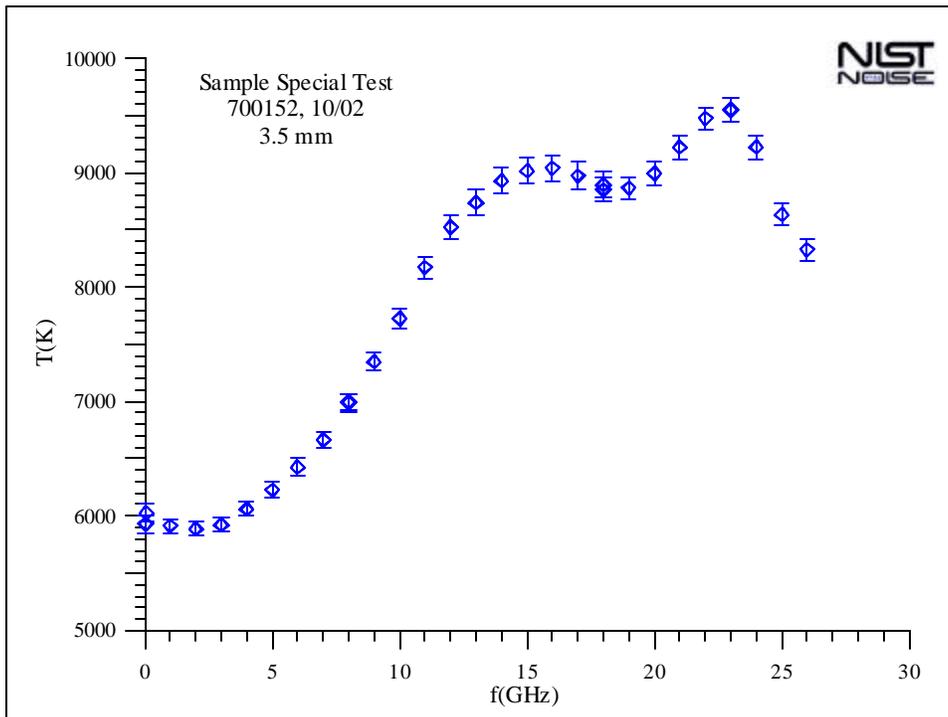


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Primary Standards

- Ambient standard: matched load, water jacket, thermistor, thermal paste. $u_{Ta} = 0.1 \text{ K}$
- Cryogenic standards: liquid nitrogen, both coaxial & waveguide.
 - $u_{TC} \approx 0.2 \text{ K}$ (waveguide)
 - 0.6 K (coaxial)

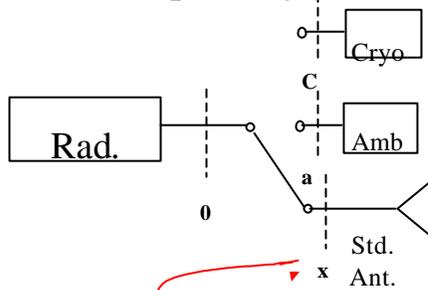




III. REMOTE-SENSING RADIOMETER CALIBRATION



- Link to primary noise standards (traceability)



$$\overline{T}_{ML} = \frac{\int T_B(\mathbf{q}, \mathbf{f}) F_n(\mathbf{q}, \mathbf{f}) dW}{\int_{main} F_n(\mathbf{q}, \mathbf{f}) dW}$$

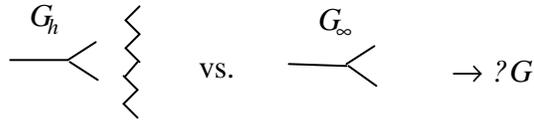
$$\overline{T}_{SL} = \frac{\int T_B(\mathbf{q}, \mathbf{f}) F_n(\mathbf{q}, \mathbf{f}) dW}{\int_{other} F_n(\mathbf{q}, \mathbf{f}) dW}$$

$$\overline{T}_{ML} = \frac{1}{ah_M} T_{A,out} - \frac{(1-h_M)}{h_M} \overline{T}_{SL} - \frac{(1-a)}{ah_M} T_a$$

$$h_M \equiv \frac{\int_{main} F_n(\mathbf{q}, \mathbf{f}) dW}{W_p}$$

- So, normal noise temperature measurement
 - + antenna pattern
 - + antenna loss
 - + environmental complications (shielding)
(note: can choose antenna for ease of characterization.)
- Future (?): standard target as a check and as a (trans)portable facility.

- Uncertainties
 - Major goal is to develop a general, standard form for uncertainty analysis for remote sensing radiometry (w. J. Piepmeier & P. Racette). Also examining individual contributions.
 - Detector nonlinearity (Dave Walker & Jeff Piepmeier)
 - Target reflectivity:



$$T_x - T_a = (T_x - T_a)_0 (1 + d_1) + D_2 + D_3,$$

$$(T_x - T_a)_0 = \frac{(p_x - p_a)}{(p_h - p_a)} (T_h - T_a),$$

$$d_1 = \frac{M_h}{M_x} - 1,$$

$$d_1 \cong 2 \operatorname{Re}[(G_r - G_\infty) DG],$$

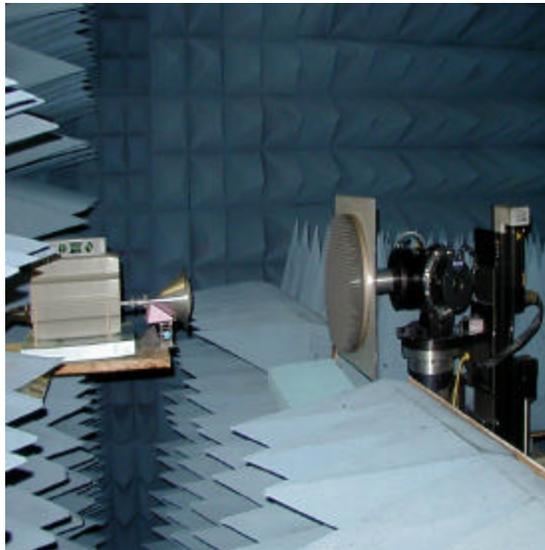
$$D_2 = -\frac{M_h}{M_x} \frac{(M_x - M_h) P_a}{(p_h - p_a)} (T_h - T_a),$$

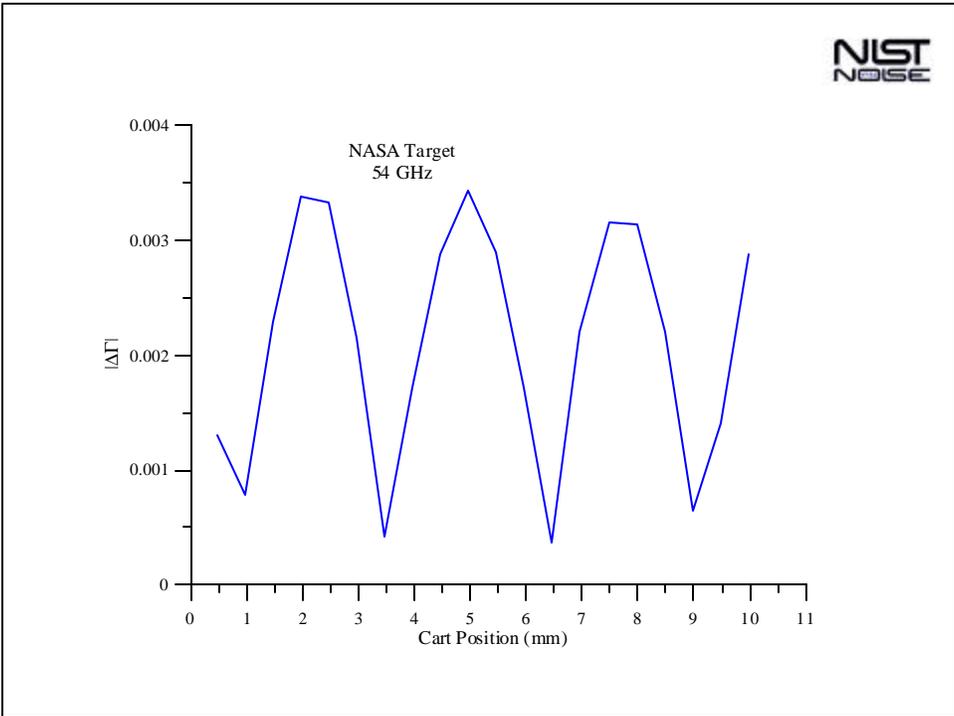
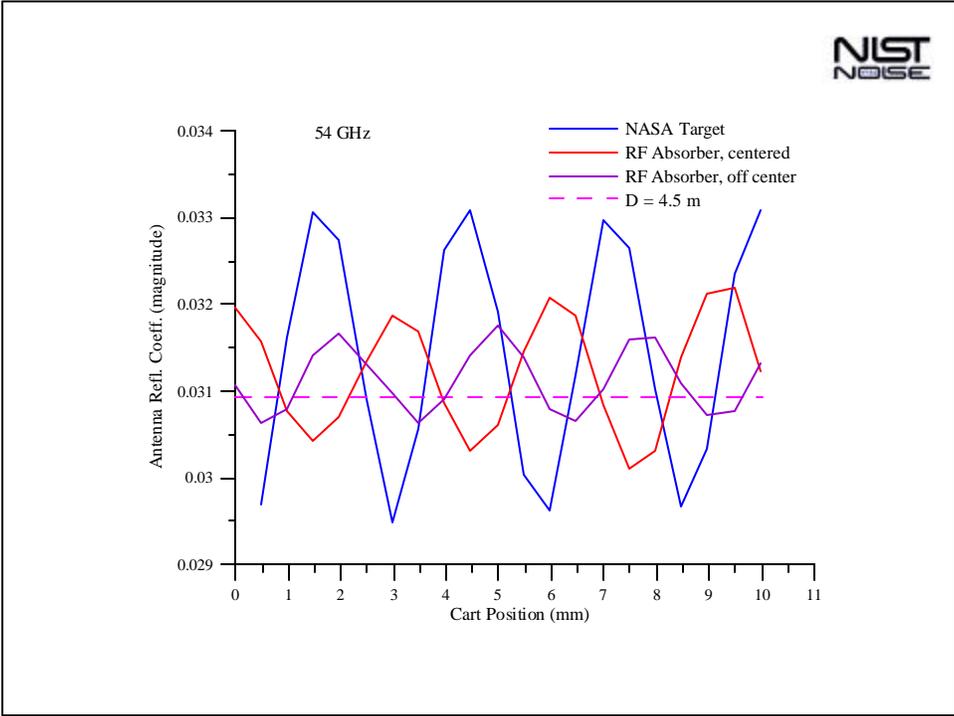
$$D_2 \cong 2 T_a \operatorname{Re}[(G_r - G_\infty) DG],$$

$$D_3 = -\frac{M_h}{M_x} \frac{(p_{e,x} - p_{e,a})}{(p_h - p_a)} (T_h - T_a).$$

$$D_3 \cong 2 X_1 \operatorname{Re}(G_\infty DG) + 2 \operatorname{Re}(X_{12} DG).$$

Borrowed target (NASA) & antenna (NOAA) & measured G_h and G_∞ in NIST anechoic chamber.





For $|G_r|=0.1$ and RMS relative phase,

$$d_1 \approx 3 \times 10^{-4},$$

$$D_2 \approx 0.08 \text{ K},$$

$$D_3 \approx 0.003 \times |X_{12}|.$$

D_3 is potentially several tenths of a kelvin.

IV. SUMMARY

- Continuing to offer noise-temperature measurement services, 30 & 60 MHz, 1 - 65 GHz.
- Transforming current radiometers into “standard radiometers” for measurements of remote sensing calibration targets.
- Also working on aspects of uncertainty analysis for remote sensing radiometry.



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www.boulder.nist.gov/div813/noise.htm